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TCLP as a Measure of Treatment Effectiveness

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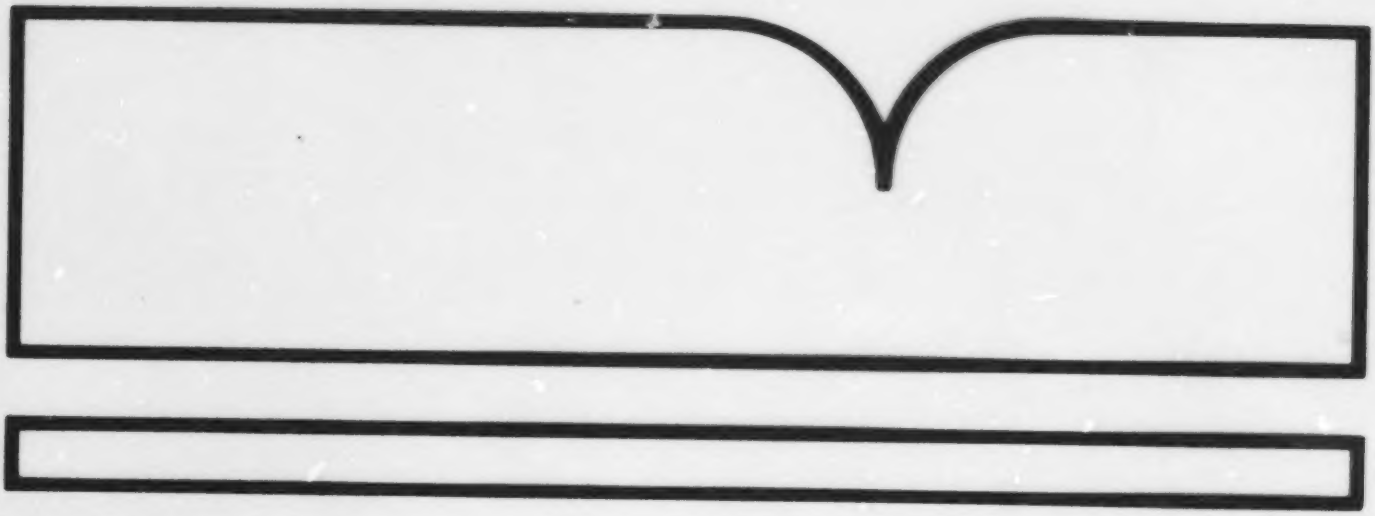

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16. ABSTRACT

The 1984 Hazardous and Solid Waste Amendments (HSWA) of the Resources Conservation and Recovery Act (RCRA) require that EPA either ban the disposal of hazardous wastes to the land or ascertain that such wastes are acceptable for land disposal. The soil and debris associated with the clean up of Superfund sites also fall under these statutes and msut be addressed. A significant part of the regulatory strategy adopted by EPA involved the determination of best demonstrated available technology for contaminated soils and debris. A series of soil treatment technologies that were considered as candidates for Superfund sites (physical, chemical, thermal solidification) were tested on a laboratory prepared feed sample and the waste product streams generated were processed by the Toxicity Characteristic Leaching Procedure (TCLP).

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TCLP as a Measure of Treatment Effectiveness

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ABSTRACT

The 1984 Hazardous and Solid Waste Amendments (HSWA) of the Resource Conservation and Recovery Act (RCRA require that EPA either ban the disposal of hazardous wastes to the land or ascertain that such wastes are acceptable for land disposal. The soil and debris associated with the clean up of Superfund sites also fall under these statutes and must be addressed. A significant part of the regulatory strategy adopted by EPA involved the determination of best demonstrated available technology for contaminated soils and debris. A series of soil treatment technologies that were considered as candidates for Superfund sites (physical, chemical, thermal solidification) were tested on a laboratory prepared feed sample and the waste product streams generated were processed by the Toxicity Characteristic Leaching Procedure (TCLP).

The TCLP chemicals and mechanism have been compared to some of the most severe leaching conditions experienced in the land disposal of hazardous wastes, and therefore the results of these tests should simulate the worst case situations. In this context, TCLP was studied as an indicator of treatment effectiveness, and may be one of the criteria employed to determine if a waste is banned or land disposed. This paper presents the TCLP data generated from five (5) different treatment technologies tested and helps to put the use of this technique into practical perspective.

INTRODUCTION

Under Section 3001 of the Resource Conservation and Recovery Act (RCRA) EPA was charged with identifying those wastes which, if improperly managed, would pose a hazard to human health and the environment. The statute also specified that EPA identify such wastes through the development of lists of hazardous waste characteristics. Characteristics are those properties which, if exhibited by a waste, identify it as a hazardous waste. The Extraction Procedure Toxicity Characteristic (EPTox) was developed to determine if specified metals, insecticides and herbicides could be mobilized from a waste by a simulated acidic leachate solution, and in turn be released to the groundwater. This condition

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simulates a worst case situation that the waste would experience in a landfill. As with most first generation rules, improvement and expansion followed. The Toxicity Characteristic Leaching Procedure (TCLP) (Ref. Federal Register, Vol. 51 14.216, Nov. 7, 1986) was subsequently developed to address the mobility of a broader range of both organic and inorganic compounds and to solve the operational problems of the EPTox protocol.

The work reported in this paper centers around a contaminated soil that was synthetically prepared to simulate the soils found at typical Superfund sites. The soil referred to herein as Synthetic Soil Matrix (SSM) was processed through five different treatment technologies: incineration, low temperaeture thermal desorption, chemical treatment, soil washing and stabilization. The performance of each technology was evaluated by comparing the results of TCLP analyses on the starting materials to the treated residues.

TOXICITY CHARACTERISTIC LEACHING PROCEDURE

The TCLP protocol for solid wastes, soils and sludges calls for a sample to be reduced in size if necessary (<9.5 mm), weighed, and mixed with an acidic solution at least 20 times the weight of the sample. The mixture is extracted for 18 hours then filtered, and the extract is retained for chemical analysis. The procedure is modified somewhat when volatile organics are involved in that a zero headspace specific extraction vessel is required. A TCLP flow chart is presented as Figure 1.

EXPERIMENTAL

The basic composition of the soil used in the technology evaluations was determined as a result of an extensive literature search of Superfund records. The final soil composition selected consisted of (by volume): 30% clay (montmorillinite and kaolinite), 25% silt, 20% sand, 20% top soil and 5% gravel. The components were air dried, and then mixed together in a standard truck-mounted cement mixer. Next, a prescribed list of chemicals found to be widely and frequently occurring as contaminates at Superfund sites was added to the clean soil to produce the SSM. This was done in a series of small scale mixing operations utilizing 500 lbs. of soil per batch and a 15 ft^3 mortar mixer. The organic components added were: acetone, chlorobenzene, 1,2-dichloroethane, ethylbenzene, styrene, tetrachloroethylene, xylene, anthracene, bis(2-ethylhexyl) phthalate and pentachlorophenol. The metals added to the clean soil were either salts or oxides of arsenic, cadmium, chromium, copper, lead, nickel, and zinc. Due to the fact that the contaminant profiles of Superfund soils differ widely from site to site in composition and concentration, four different SSM formulations were prepared. Table 1 presents the target contaminant concentration levels for each of the four SSM formulations as well as the actual levels achieved as measured by total waste analysis (TWA) of the finished product. The TWA analyses showed that the SSMs exhibited satisfactory consistency and homogeneity between formulations and approached the desired target levels. Readers should note that Table 1 presents total contaminant levels in the SSMs rather than TCLP values (which are discussed later). The data is presented to show how well the target levels were achieved and some of the analytical uncertainty that goes along with this type of research; it is not intended to confuse the objective of the study.

The SSMs produced in the first phase of this project were then processed through five treatment technologies that were 1) most readily available for use in the field at the time (1987) and 2) had the greatest applicability to CERCLA site restoration activities. The technologies studied were: incineration, low temperature thermal desorption, chemical treatment (KPEG), physical treatment (soil washing) and solidification/stabilization. The effectiveness of the five different treatment technologies was determined by measuring the concentration of the target compounds and elements in the untreated soil versus that of the treated

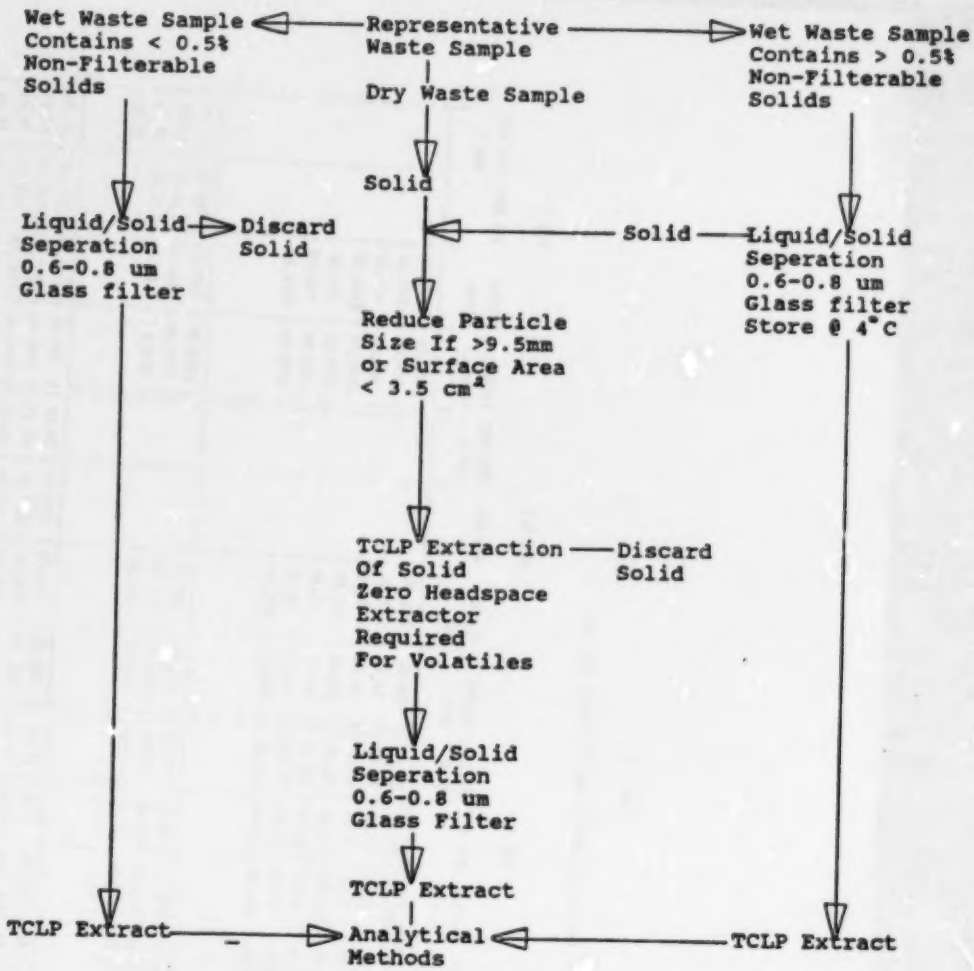

FIGURE 1 TCLP FLOWCHART

residues. Concentration changes were measured by both TWA and by TCLP. The logic behind the TCLP aspect of the project was that if the treatment reduced or immobilized the contamination to a point where it would not migrate with the acidic leachate, the residual would be a good candidate for land disposal. Thus, residuals from each of the treatment technologies were collected and processed through the TCLP, and analyzed for the metals and organic compounds listed above.

RESULTS

Table 2 presents TCLP data for the untreated SSM-I soil. The data which were collected from extraction of six different samples and 12 separate TCLP analyses, indicate that the synthetic matrix itself was a good binder. Overall contaminant concentrations in the TCLP extract were about 30% of the total a maximum available

TABLE 1

TARGET AND ACTUAL CONCENTRATIONS FOR SSMs

COMPOUND	SSM I TARGET MG/KG	SSM I ACTUAL MG/KG	SSM I STD DEV	SSM I REL STD DEV %	SSM II TARGET MG/KG	SSM II ACTUAL MG/KG	SSM II STD DEV	SSM II REL STD DEV %	SSM III TARGET MG/L	SSM III ACTUAL MG/L	SSM III STD DEV	SSM III REL STD DEV %	SSM IV TARGET MG/KG	SSM IV ACTUAL MG/KG	SSM IV STD DEV	SSM IV REL STD DEV %
ACETONE	6800.00	4353.00	1933.00	44.40	680.00	357.00	184.00	51.54	680.00	358.00			6800.00	3059.00		
CHLOROBENZENE	400.00	316.00	49.00	15.50	40.00	13.20	10.40	78.79	40.00	11.00			400.00	329.00		
1,2-DICHLOROETHANE	600.00	354.00	143.00	40.40	60.00	4.60	3.80	82.61	60.00	4.90			600.00	491.00		
ETHYLBENZENE	3200.00	3329.00	654.00	19.70	320.00	123.00	111.00	90.24	320.00	144.00			3200.00	2708.00		
STYRENE	1000.00	707.00	96.00	13.60	100.00	48.00	38.00	79.17	100.00	32.30			1000.00	631.00		
TETRACHLOROETHYLENE	600.00	459.00	137.00	29.90	60.00	19.00	11.00	57.89	60.00	20.10			600.00	540.00		
XYLENE	8200.00	5555.00	1921.00	34.60	820.00	165.00	72.00	43.64	820.00	325.00			8200.00	5576.00		
ANTHRACENE	6500.00	5361.00	3785.00	70.60	650.00	353.00	97.00	27.48	650.00	181.00			6500.00	1920.00	1992.00	103.75
BIS(2-ETHYLHEXYL)P	2500.00	1958.00	1104.00	56.40	250.00	136.00	120.00	88.24	250.00	114.00			2500.00	646.00	284.00	43.96
PENTACHLOROPHENOL	1000.00	326.00	237.00	72.70	100.00	39.00	55.00	141.03	100.00	30.00			1000.00	80.00	23.00	28.75
																58.82
ARSENIC	10.00	19.00	7.00	36.80	10.00	17.40	2.00	11.49	500.00	702.00	204.00	29.06	500.00	562.00	174.00	30.96
CADMIUM	20.00	23.00	10.00	43.50	20.00	2404.00	3.10	0.13	1000.00	1934.00	1352.00	69.91	1000.00	2897.00	2819.00	97.31
CHROMIUM	30.00	26.00	7.00	26.90	30.00	283.00	5.00	1.77	1500.00	1204.00	163.00	13.54	1500.00	1381.00	172.00	12.45
COPPER	190.00	239.00	56.00	23.40	190.00	259.00	48.00	18.53	9500.00	9196.00	1551.00	16.87	9500.00	11102.00	1811.00	16.31
LEAD	280.00	245.00	62.00	25.30	280.00	305.00	58.00	19.02	14000.00	14695.00	1507.00	10.26	14000.00	15178.00	2227.00	14.67
NICKEL	30.00	33.00	17.00	51.50	30.00	35.40	15.20	42.94	1000.00	1419.00	578.00	40.73	1000.00	1459.00	616.00	42.22
ZINC	450.00	502.00	218.00	43.40	450.00	418.00	179.00	42.82	22500.00	36177.00	11878.00	32.83	22500.00	27428.00	5472.00	19.95

TABLE 2

TCLP FOR SSM1 - UNTREATED SOIL, MG/L

COMPOUND	MEAN	STD DEV		MAXIMUM EXTRACTABLE	EXTRACTED TCLP %
ACETONE	207	70	(12)	218.0	95
CHLOROBENZENE	7.3	0.8	(12)	15.8	46
1,2-DICHLOROETHANE	22.3	5.5	(12)	17.7	126
ETHYLBENZENE	45.7	8.4	(12)	166.5	28
STYRENE	11.0	3.1	(12)	35.4	31
TETRACHLOROETHYLENE	6.6	1.7	(12)	23.0	29
XYLENE	81.0	10.5	(12)	278.0	29
ANTHRACENE *	19.4*	18	(12)	266.0	0.01
BIS(2-ETHYLHEXYL) PH*	26.5*	27	(12)	97.9	0.02
PENTACHLOROPHENOL	4.1	3.7	(12)	16.3	25
ARSENIC	0.09	0.07	(12)	0.95	9
CADMIUM	0.67	0.21	(12)	1.15	58
CHROMIUM	0.06	0.04	(12)	1.3	5
COPPER	3.50	1.8	(12)	12.0	29
LEAD	1.60	0.8	(12)	12.3	13
NICKEL	0.55	0.22	(12)	1.65	34
ZINC	12.5	4.5	(12)	25.1	49

NOTE ( ) = NUMBER OF DETERMINATIONS USED TO DETERMINE THE MEAN AND STANDRAD DEVIATION

* = UG/L

for leaching.* The volatiles (as a group) were extracted at 55% of the maximum, the metals at 20% and the semivolatiles at 8%. In theory, the application of TCLP to the organic fraction of a sample predicts that very little of the higher boiling, hydrophobic organic compounds such as anthracene or pentachlorophenol will be present in the extract. This was observed in the TCLP data. The volatile fraction was more extractable than the semivolatile fraction, and if the boiling points of each of the volatiles are compared with the percentage extracted, Figure 2 results, showing a trend toward lower TCLP extraction efficiency as the boiling point of the compounds increases. This type of information can be useful in determining the minimum soil concentration levels that would be necessary for using TCLP as a predictive tool for residual organic compounds earmarked for land disposal.

The main thrust of the project was to evaluate the treatment effectiveness of the five different technologies, by either destroying, removing or containing the pollutants of interest. One of the ways to judge the effectiveness was to compare the leachability of the target compounds after treatment with similar data before treatment. TCLP was the vehicle selected to make this comparison. In making this selection it should be remembered that the initial TCLP values for untreated SSMs were in several cases quite small (see Table 2) and often near the limit of analytical detection. Thus, in many cases the treatment effectiveness was judged on the difference between two small numbers. With these thoughts in mind, the TCLP data generated for the five CERCLA treatment technologies is presented.

*Maximum estimated at 1/20th the average total concentration shown in Table 1.

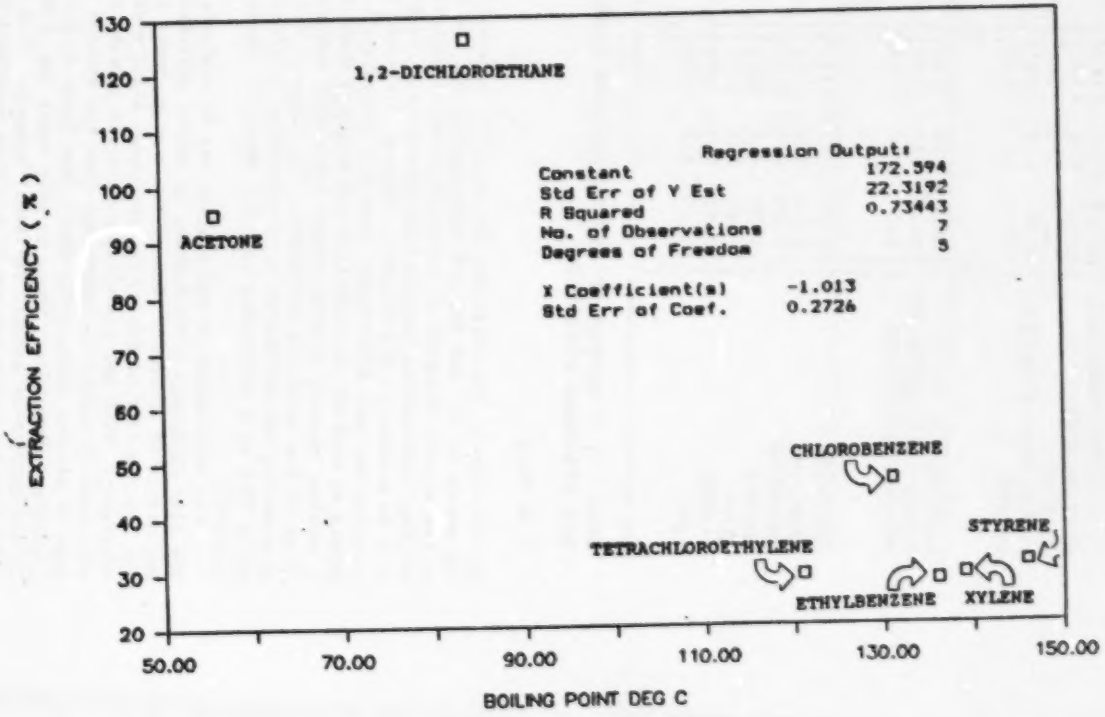
EXTRACTION EFFICIENCY (%)
130
120
110
100
90
80
70
60
50
40
30
20
1,2-DICHLOROETHANE
ACETONE
Regression Output:
Constant 172.594
Std Err of Y Est 22.3192
R Squared 0.73443
No. of Observations 7
Degrees of Freedom 5
X Coefficient(s) -1.013
Std Err of Coef. 0.2726
CHLOROBENZENE
STYRENE
TETRACHLOROETHYLENE
ETHYLBENZENE
XYLENE
50.00
70.00
90.00
110.00
130.00
150.00
BOILING POINT DEG C

FIGURE 2

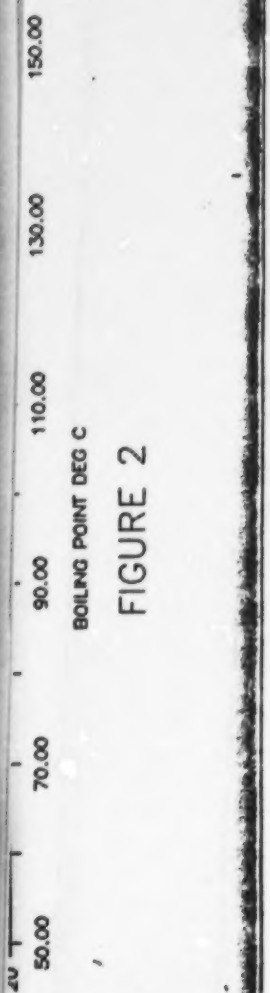

FIGURE 2

Stabilization/Solidification

Table 3 presents some typical TCLP data collected from the solidification experiments. SSM-I was treated with either portland cement, kiln dust, or a lime/fly ash mixture and cured for 28 days. The stabilized materials were then analyzed by TCLP. Each of the individual chemicals in the TCLP extract from the treated residuals were compared to the initial TCLP concentrations for the untreated SSM and the individual removal efficiencies were calculated. Appropriate adjustments were made to account for dilution when the binders were added to the SSM. These efficiencies were summed and averaged for each class of compounds (volatiles etc.) and the average number taken as the overall effectiveness attributable to stabilization treatment. It appears that portland cement, lime/flyash and kiln dust are all good binders, reducing leachable metals by 95 percent. Table 3 also contains some proposed TCLP health and safety numbers; their purpose is to serve as guidelines to potential environmental problems. These numbers are related to the health-based drinking water standards with the attenuation factor of 100 added to simulate release from a landfill and percolation through the ground to the water table. As of now, these numbers do not have any regulatory significance from a Superfund perspective.

Low-Temperature Thermal Desorption

The purpose of this research was to investigate the capability of a laboratory-scale low-temperature thermal desorption technology for removing volatile and semivolatile contaminants from the soils. The laboratory testing program consisted of 25 separate bench-scale tests (20 in a tray furnace and 5 in a tube furnace). SSM-I and SSM-II were tested at 150°, 350°, and 550°F for 30 minutes to determine the effect of each temperature on removal of the contaminants. The tray furnace was used as a baseline technology to determine the overall effectiveness of thermal desorption in removing contaminants from the soil.

Table 4 presents TCLP data collected for the low temperature thermal desorption study on SSM-I. Each of the residues were analyzed for the individual chemicals and the results compared with the TCLP values for the untreated SSM-I. This data was examined in the same way as described under the solidification data. The removal efficiencies for the volatiles as a group increased with increasing temperature, reaching the 99% reduction level at 230°F and the 99.5% reduction level at 300°F. The data for the low temperature treatment of the semivolatiles was less clear, although a trend toward increased removal with higher temperatures was observed. TCLP tests for the metals in the residues of the low temperature thermal desorption experiments showed an increase in concentration in the extract, compared to the untreated soil, especially at the lower temperature. The warming of the matrix and the liberation of the organics and moisture appear to have made the metals more ammenable to TCLP extraction.

Chemical Dechlorination/KPEG

Chemical declorination was examined as a treatment technology because it had already been successfully demonstrated at laboratory scale with PCB- and dioxin-contaminated soils and sludges, and was viewed as a promising treatment technology for development to pilot scale and possibly full scale. The KPEG dechlorination process involves the application of a potassium hydroxide-polyethylene glycol reagent to contaminated soil at elevated temperatures for a period of 2 to 4 hours, after which the reagent is decanted and recovered and the soil is rinsed and neutralized. The reagent strips one or more chlorine atoms from the PCB or dioxin molecule, forming an inorganic chloride salt and a derivative of the PCB or dioxin, which, in theory, should be less toxic than the original contaminant.

TABLE 3

TCLP DATA SUMMARY FOR STABILIZATION OF SSM-I, MG/L

COMPOUND	TCLP HEALTH & SAFETY VAL	INITIAL VALUE	STD DEV	SSM1 PORT CEMENT	REDUCTION %	SSM1 KILN DUST	REDUCTION %	SSM1 LIME-FLY/ASH	REDUCTION %
ACETONE		207.0	70.0	180.00	13.00	6.10	97.10	43.00	79.20
CHLOROBENZENE	1.40	7.3	0.8	1.30	82.20	0.06	99.20	1.60	78.10
1,2-DICHLOROETHANE	0.40	22.3	5.5	<0.44	>98.00	0.10	99.60	<0.10	>99.60
ETHYLBENZENE		45.7	8.4	10.30	77.50	<0.06	>99.90	18.00	60.60
STYRENE		11.0	3.1	<2.80	>74.50	1.06	90.40	4.10	62.70
TETRACHLOROETHYLENE	0.10	6.6	1.7	0.72	89.10	<0.02	>99.70	1.50	77.30
XYLENE		81.0	10.5	13.80	83.00	2.04	97.50	22.00	72.80
				AVG	>73.90	AVG	>97.63	AVG	>75.76
ANTHRACENE *		19.4*	18.10	<0.03*	>99.84	<0.05	>99.80	<0.02	>99.90
BIS(2-ETHYLHEXYL)PH*		26.5*	27.00	1.02*	96.20	<0.05	>99.80	0.16	99.40
PENTACHLOROPHENOL	3.60	4.1	3.70	<3.87	>5.60	<0.13	>96.80	0.40	90.20
				AVG	>67.21	AVG	>98.80	AVG	>96.50
ARSENIC	5.00	0.09	0.07	<0.15	NR	<0.15	NR	<0.15	NR
CADMIUM	1.00	0.67	0.28	<0.01	>98.50	<0.01	>98.50	<0.01	>98.50
CHROMIUM	5.00	0.06	0.04	0.06	NR	0.09	NR	0.02	NR
COPPER		3.50	1.80	<0.06	>98.30	0.03	99.10	0.03	98.30
LEAD	5.00	1.60	0.80	<0.15	>90.60	<0.15	>90.50	<0.15	>90.60
NICKEL		0.50	0.22	<0.04	>92.70	<0.04	>92.70	<0.04	>92.70
ZINC		12.50	4.50	0.49	96.10	0.62	95.00	<0.01	>99.90
				AVG	>95.20	AVG	>95.10	AVG	>96.00

* = UG/L
NR = NOT REPORTED

NICKEL		0.50	0.22	<0.04	>92.70	<0.04	>92.70	<0.01	>99.90
ZINC		12.50	4.50	0.49	96.10	0.62	95.00		
				AVG	>95.20	AVG	>95.10	AVG	>96.00

* = UG/L
NR = NOT REPORTED

TABLE 4

TYPICAL TCLP DATA SUMMARY FOR LOW TEMPERATURE
THERMAL DESORPTION OF SSM-1, MG/L

	TCLP HEALTH & SAFETY	INITIAL VALUE	TREATMENT @ 150 F	REDUCTION %	TREATMENT @ 350 F	REDUCTION %	TREATMENT @ 550 F	REDUCTION %
ACETONE		207.00	20.00	90.30	1.90	99.10	1.00	99.50
CHLOROBENZENE	1.40	7.30	2.90	60.30	<0.10	>98.60	<0.10	>98.60
1,2-DICHLOROETHANE	0.40	223.00	0.40	98.20	<0.10	>99.60	<0.10	>99.60
ETHYLBENZENE		45.70	44.00	3.70	<0.10	>99.80	<0.10	>99.80
STYRENE		11.00	3.10	99.00	<0.10	>99.10	<0.10	>99.10
TETRACHLOROETHYLENE	0.10	6.60	1.30	80.30	<0.10	>98.50	<0.10	>98.50
XYLENE		81.00	55.10	32.10	0.11	99.90	<0.10	>99.90
			AVG	66.27	AVG	>99.23	AVG	>99.29
ANTHRACENE *		19.40	<0.02	>99.90	0.86	95.60	<0.01	>99.90
BIS(2-ETHYLHEXYL)P*		26.50	0.16	99.40	0.78	97.10	<0.03	>99.90
PENTACHLOROPHENOL	3.60	4.10	1.61	60.60	5.27	28.80	0.35	91.40
			AVG	>86.63	AVG	73.83	AVG	>97.07
ARSENIC	5.00	0.09	<0.15	NR	<0.15	NR	<0.15	NR
CADMIUM	1.00	0.67	1.30	(94)	1.10	(64.2)	0.90	(34)
CHROMIUM	5.00	0.06	0.10	(67)	0.13	(116)	0.04	67.00
COPPER		3.50	6.80	(94)	5.13	(46.6)	0.04	99.00
LEAD	5.00	1.60	2.80	(75)	2.30	(43.8)	0.20	88.00
NICKEL		0.50	1.40	(180)	1.10	(120)	0.60	(20)
ZINC		12.50	27.30	(118)	24.00	(92)	13.80	(10)
			AVG	(105)	AVG	(80)	AVG	32

( ) INDICATE A NEGATIVE REDUCTION
* = UG/L
NR= NOT REPORTED

Each of the four synthetic soils was evaluated in this study. Although the soils did not contain any PCB's or dioxins, other chlorinated species were present, and there was interest in learning whether these compounds could be dechlorinated. There was also interest in learning whether the process would exhibit any removal effectiveness on the other organic and inorganic contaminants in the test soils.

Testing was conducted in either 500-ml or 2-liter glass reaction vessels mounted within temperature-controlled heating mantles. In each test, either 125 or 500 g of soil was treated with KPEG reagent at 100°C for 2 hours. During the reaction period, the contents of the glass reaction vessel were continually stirred at 100 rpm with a Teflon-coated stainless steel stirring rod. The system was also continually purged with nitrogen, and the off-gases were filtered through a Tenax/XAD-2/carbon trap system. The contents of the traps were subsequently analyzed to establish material balances and to determine which compounds had been destroyed versus those which had simply been volatilized. At the end of the 2-hour reaction period, the reagent was separated from the soil by centrifugation and decantation. The soil was then neutralized by an acid rinse followed by a plain water rinse. All rinse solutions, soil residues, and the spent reagent were analyzed for the target soil contaminants. The residues from these tests were also analyzed by TCLP.

Table 5 summarizes the TCLP data collected on the residue collected from the chemical treatment of the SSM-I using the KPEG reagent. The TCLP data indicate that the KPEG process was effective in reducing the volatiles from the soil;

TABLE 5

TYPICAL TCLP DATA SUMMARY FOR CHEMICAL TREATMENT OF SSM-I, MG/L

	TCLP HEALTH & SAFETY VAL	INITIAL VALUE	TREATED VALUE	REDUCTION %
ACETONE		207.00	4.70	97.73
CHLOROBENZENE	1.40	7.30	0.80	89.04
1,2-DICHLOROETHANE	0.40	22.30	<0.10	>99.55
ETHYLBENZENE		45.70	8.10	82.28
STYRENE		11.00	2.80	74.55
TETRACHLOROETHYLENE	0.10	6.60	0.10	98.48
XYLENE		81.00	10.70	86.79
			AVG	>89.77
ANTHRACENE *		19.4*	<0.02	>99.90
BIS(2-ETHYLHEXYLPH*		26.5*	<0.15	>99.43
PENTACHLOROPHENOL	3.60	4.1	<0.05	>98.78
			AVG	>99.37
ARSENIC	5.00	0.09	<0.01	>88.88
CADMIUM	1.00	0.67	0.28	58.21
CHROMIUM	5.00	0.06	<0.01	>83.33
COPPER		3.50	0.24	93.14
LEAD	5.00	1.60	0.64	60.00
NICKEL		0.50	0.23	54.00
ZINC		12.50	0.39	96.88
			AVG	>76.35

* = UG/L

however data collected from the material balance clearly indicated that the volatiles were driven off by the process rather than dechlorinated by the KPEG reagent. 1,2-Dichloroethane was an exception.

The semivolatile results indicate that the soil was again treated very effectively by the KPEG reagent. However, analysis of all the waste streams collected showed that the semivolatiles were washed off the soil not destroyed by the KPEG reagent. The TCLP data for the KPEG treated soil suggest that the KPEG process was successful in removing both organic and inorganic contaminants from the soils, but its effectiveness relative to dechlorination was quite limited.

Physical Separation/Volume Reduction (Soil Washing)

As part of the performance evaluation of this technology, samples of each synthetic soil were physically treated in a series of bench-scale washing experiments designed to simulate the EPA-developed pilot-scale Mobile Soils Washing System (MSWS). This system physically separates contaminated fines from coarse soil material, which effectively reduces the volume of the contaminated portion of the soils.

Specifically, this project was designed to simulate the drum-screen washer segment of the MSWS. This segment separates the >2-mm soil fraction (coarse material) from the <2-mm soil fraction (fines) by use of a rotary drum screen. A high-pressure water knife operates at the head of the system to break up soil lumps and strip the contaminants from the soil.

The soils were tested by evaluating different wash solutions in a series of bench-scale shaker-table experiments. Two wash solutions were chosen for evaluation: 1) a chelant solution (tetrasodium salt of EDTA, Dow Chemical Versene 100^{R}), and 2) an anionic surfactant solution (phosphated formulation from Procter & Gamble, Institutional Formula Tide^{R}). Following shaker-table washing, each synthetic soil was wet-sieved to separate the fines from the coarse material. Although the EPA MSWS only separates the soil into ≥2-mm and <2-mm size fractions, three size fractions (>2-mm, 0.25-2mm, and <.25 mm) were investigated in this study to determine if the middle fraction (medium to fine sand) could be cleaned effectively, thereby increasing the volume reduction efficiency.

Table 6 presents typical data from the soil washing tests on the medium sized (0.25-2mm) fraction of SSM I, and Table 7 summarizes all of the TCLP soils washing results for all four SSM formulations. The TCLP data indicate that the largest sized fraction (>2mm) could be effectively treated (TCLP reductions of 88-99% were typical for both organics and metals), however the smallest fraction (<0.25mm) could not be effectively treated for semivolatiles and metals.

High-Temperature Incineration

In this segment of the test program, a series of pilot-scale test burns was conducted with SSM-I and -II only. The testing was conducted at the John Zink testing facility in Tulsa, Oklahoma, in a rotary kiln incineration system using a nominal feed rate of 1000 lb SSM/h. More than 12,000 pounds of each soil was prepared for the tests so that three 4-hour test burn runs could be conducted on each. Approximately 1 week prior to startup of the test burns, the soils were delivered to John Zink in forty-eight 55-gallon steel drums, each containing 500 to 600 lb.

The process operating data collected during each test show that the temperatures and feed rates achieved were reasonably close to the goals (i.e., 1800°F in the kiln, 2000°F in the secondary combustion chambers, and a nominal feed rate of 1000 lb/h). Excess air was maintained at about 3 percent in the kiln and about 5 percent in the secondary chamber during both tests. Emissions of O_2, CO_2, and CO were steady throughout; CO remained at less than 10 ppm. A total of 13,932 lb of SSM-I and 13,460 lb of SSM-II were incinerated over a course of 3 days that involved 29 hours 22 minutes of testing.

TABLE 6

TCLP DATA SUMMARY FOR SOILS WASHING TREATMENT ON SSH-I
MID-SIZED FRACTION (0.25MM PARTICLE SIZE), MG/L

	TCLP HEALTH & SAFETY VAL	INITIAL VALUE	WATER TREATED VALUE	REDUCTION %	SURFACTANT TREATED VALUE	REDUCTION %
ACETONE		207.00	0.74	99.64	0.65	99.69
CHLOROBENZENE	1.40	7.30	<0.04	>99.45	0.12	98.36
1,2-DICHLOROETHANE	0.40	22.30	<0.10	>99.55	<0.10	>99.55
ETHYLBENZENE		45.70	0.33	99.28	0.97	97.88
STYRENE		11.00	<0.10	>99.09	0.25	97.73
TETRACHLOROETHYLENE	0.10	6.60	<0.10	>98.48	<0.10	>98.48
XYLENE		81.00	0.91	98.88	2.20	97.28
			AVG	>99.25		@ >98.48
ANTHRACENE *		19.40	<0.10	>99.48	<0.02	>99.89
BIS(2-ETHYLHEXYLPH*		26.50	<0.04	>99.85	<0.10	>99.62
PENTACHLOROPHENOL	3.60	4.10	1.10	73.17	0.41	90.00
			AVG	>91.03	AVG	>96.51
ARSENIC	5.00	0.09	<0.15	NR	<0.15	NR
CADMIUM	1.00	0.67	0.40	40.30	0.26	61.19
CHROMIUM	5.00	0.06	<0.01	>83.33	<0.01	>83.33
COPPER		3.50	0.28	92.00	0.18	94.85
LEAD	5.00	1.60	0.22	86.25	0.15	90.63
NICKEL		0.50	<0.09	>82.00	<0.06	>88.00
ZINC		12.50	3.25	74.00	1.90	84.80
			AVG	>76.3	AVG	>83.79

* = UG/L

Table 8 presents TCLP results for the feedstock soil and bottom ash samples collected during each test run. Referring back to Table 1 the difference in initial concentration of the contaminant compounds and the resulting TCLP extraction coefficient shows up dramatically in the performance levels as measured by TCLP reductions. For example, measureable amounts of acetone, ethylbenzene and xylene show up in the TCLP for the ash of both soils; their presence leads to calculated reductions of 95-99%, which is 2 orders of magnitude less than 4-nines (99.99%) removal concept that currently guides incineration performance.

The metals data also reflect the two different SSM concentration levels in that the arsenic and chromium initial levels were near detection limits in the untreated soil. Assigning a treatment value on the basis of the difference between two small numbers should be done with caution. The metals data does show, however, that the mobility of most of the metals in the treated soil residues has been significantly decreased and these solids do not appear to pose a migration/leachate problem for land disposal.

DISCUSSION

The use of TCLP as a tool for measuring treatability performance of a particular technology and its application to CERCLA soils was presented. On the

TABLE 7

TYPICAL TCLP DATA SUMMARY FOR SOILS WASHING
(OVERALL PERCENT REDUCTION BY CONTAMINANT GROUP)

PARTICLE SIZE		SSH-I		SSH-II			SSH-III		SSH-IV		
		WATER	SURFACT	WATER	SURFACT	CHELATE	WATER	CHELATE	WATER	SURFACT	CHELATE
2MM	VOLATILES	98.9	98.8	0	47.7	74.3	96.8	92.2	99.7	99.3	99.1
	SEMIVOLATILES	98.6	98.1	95.6	94.7	94.7	54.5	86.4	93.9	97.3	96.2
	METALS	87.4	88.6	94.6	96.4	94.7	87.4	88.7	87.4	92.6	93.3
0.2 TO 2 MM	VOLATILES	99.3	98.5	0	22.4	66.4	0	94.3	99.1	98.8	98.6
	SEMIVOLATILES	91.0	96.5	92.9	77.9	81.4	0	2.3	83.8	86.4	90.3
	METALS	76.3	83.8	55.5	74.2	92.2	84.1	93.5	67.1	70	76.9
0.25MM	VOLATILES	99.5	92.8	61.8	60.5	31.6	92.6	95.3	92.2	97	80.7
	SEMIVOLATILES	51.5	0	55.7	43.4	75.2	0	31.8	71.5	85.8	14.5
	METALS	0	0	0	0	0	0	30.9	8.6	2.5	33.4

TABLE 8

TCLP DATA SUMMARY FOR THE INCINERATION TREATMENT OF SSH-I&II, MG/L

COMPOUND	HEALTH & SAFETY VAL MG/L	SSH I INITIAL VALUE	SSH I TREATED	SSH I REDUCTION %	SSH II INITIAL VALUE	SSH II TREATED	SSH II REDUCTION %
ACETONE		207.00	0.74	99.64	13.50	0.14	98.96
CHLOROBENZENE	1.40	7.30	<0.04	>99.45	0.50	<0.10	>80.00
1,2-DICHLOROETHANE	0.40	22.30	<0.01	>99.96	0.30	<0.10	>66.67
ETHYLBENZENE		45.70	0.65	98.58	3.70	0.19	94.86
STYRENE		11.00	0.11	99.00	0.30	<0.10	>66.67
TETRACHLOROETHYLENE	0.10	6.60	<0.04	>99.39	0.40	<0.10	>75.00
XYLENE		81.00	1.05	98.70	8.10	0.23	97.16
			AVG	>99.25		AVG	>82.76
ANTHRACENE *		19.40	<0.01	>99.95	<0.02	<0.10	>50.00
BIS(2-ETHYLHEXYL)PH*		26.50	<0.01	>99.96	0.14	<0.10	>92.86
PENTACHLOROPHENOL	3.60	4.10	<0.02	>99.51	0.45	<0.02	>95.56
			AVG	>99.81		AVG	>79.47
ARSENIC	5.00	0.09	0.15	(66.67)	0.15	0.15	0.00
CADMIUM	1.00	0.67	<0.01	>98.51	0.75	<0.01	>98.67
CHROMIUM	5.00	0.06	<0.01	>83.33	0.04	<0.04	0.00
COPPER		3.50	<0.02	>99.43	2.51	0.26	89.64
LEAD	5.00	1.60	0.15	90.63	1.22	0.49	59.84
NICKEL		0.50	<0.04	>92.00	0.53	<0.05	>90.57
ZINC		12.50	<0.03	>99.76	14.10	0.15	98.94
			AVG	>93.94		AVG	>62.53

* = UG/L

TABLE 9

TCLP EVALUATION OF THE TREATMENT EFFECTIVENESS ON SSM'S I, II, III, IV

	SSM-I VOLATILES	% REDUCTION	SSM2 VOLATILES	% REDUCTION	SSM3 VOLATILES	% REDUCTION	SSM 4 VOLATILES	% REDUCTION
1	SOIL WASHING (WATER 0.25mm)	99.5	SOLIDIFICATION (LIME FLY/ASH)	88.0	SOIL WASHING (WATER 2mm)	96.8	SOIL WASHING (WATER 2mm)	99.7
2	LOW TEMP THERMAL DESORB @350 F	99.3	INCINERATION	82.8	SOIL WASHING (CHELATE 0.25mm)	95.3	SOIL WASHING (SURFACTANT 2mm)	99.3
3	INCINERATION	99.3	SOLIDIFICATION (KILN DUST)	82.0	SOIL WASHING (CHELATE 0.25-2mm)	94.3	SOIL WASHING (WATER 0.25-2mm)	99.1
4	LOW TEMP THERMAL DESORB @350 F	99.2	LOW TEMP THERMAL DESORB @150 F	81.4	SOLIDIFICATION (KILN DUST)	93.6	SOIL WASHING (CHELATE 2mm)	99.1
5	SOIL WASHING (WATER 0.25-2mm)	99.2	CHEMICAL TREATMENT (KPEG)	81.0	SOIL WASHING (WATER 0.25mm)	92.6	SOIL WASHING (SURFACTANT 0.25-2mm)	98.8
6	SOIL WASHING (WATER 2mm)	98.9	LOW TEMP THERMAL DESORB @350 F	80.8	SOIL WASHING (CHELATE 2mm)	92.2	SOIL WASHING (CHELATE 0.25-2mm)	98.6
7	SOIL WASHING (SURFACTANT 2mm)	98.8	LOW TEMP THERMAL DESORB @350 F	79.6	SOLIDIFICATION (LIME/FLY ASH)	90.3	SOIL WASHING (SURFACTANT 0.25mm)	97.8
8	SOIL WASHING (SURFACTANT 0.25-2mm)	98.5	SOIL WASHING (CHELATE 2mm)	73.4	CHEMICAL TREATMENT (KPEG)	84.2	CHEMICAL TREATMENT (KPEG)	96.2
9	SOLIDIFICATION (KILN DUST)	97.6	SOIL WASHING (CHELATE 0.25-2mm)	66.6	SOLIDIFICATION (PORTLAND CEMENT)	68.3	SOIL WASHING (WATER 0.25mm)	92.2
10	SOIL WASHING (SURFACTANT 0.25mm)	92.8	SOIL WASHING (WATER 0.25mm)	61.8			SOIL WASHING (CHELATE 0.25mm)	80.7
11	CHEMICAL TREATMENT (KPEG)	89.9					SOLIDIFICATION (KILN DUST)	77.5
12	SOLIDIFICATION (PORTLAND CEMENT)	73.9					SOLIDIFICATION (LIME/FLY ASH)	73.7
	SSM 1 SEMIVOLATILES		**SSM 2 SEMIVOLATILES**		**SSM 3 SEMIVOLATILES**		**SSM 4 SEMIVOLATILES**	
1	INCINERATION	99.8	INCINERATION	98.8	SOIL WASHING (CHELATE 2mm)	86.4	SOIL WASHING (CHELATE 2mm)	95.3
2	CHEMICAL TREATMENT (KPEG)	99.4	SOIL WASHING (WATER 2mm)	95.6	SOLIDIFICATION (KILN DUST)	82.2	SOIL WASHING (SURFACTANT 2mm)	92.6
3	SOLIDIFICATION (KILN DUST)	98.8	SOIL WASHING (CHELATE 2mm)	94.7	SOLIDIFICATION (LIME/FLY ASH)	54.8	SOLIDIFICATION (LIME/FLY ASH)	88.6
4	SOIL WASHING (WATER 2mm)	98.6	SOIL WASHING (SURFACTANT 2mm)	94.7	SOIL WASHING (WATER 2mm)	54.5	SOIL WASHING (WATER 2mm)	87.4
5	SOIL WASHING (SURFACTANT 2mm)	98.1	SOIL WASHING (WATER 0,25-2mm)	92.9	CHEMICAL TREATMENT (KPEG)	50.5	CHEMICAL TREATMENT (KPEG)	86.1
6	LOW TEMP THERMAL DESORB @350 F	97.1	LOW TEMP THERMAL DESORB @350 F	92.8	SOIL WASHING (CHELATE 0.25mm)	31.8	SOIL WASHING (CHELATE 0.25-2mm)	76.9
7	SOIL WASHING (SURFACTANT 0.25-2mm)	96.9	CHEMICAL TREATMENT (KPEG)	91.8			SOIL WASHING (SURFACTANT 0.25-2mm)	70.8
8	SOLIDIFICATION (LIME/FLY ASH)	96.5	LOW TEMP THERMAL DESORB @150 F	89.5			SOIL WASHING (WATER 0.25-2mm)	67.1
9	SOIL WASHING (WATER 0.25-2mm)	91.0	SOIL WASHING (WATER 0.25-2mm)	81.4			SOLIDIFICATION (KILN DUST)	52.7
10	LOW TEMP THERMAL DESORB @ 150 F	86.7	SOIL WASHING (CHELATE 0.25-2mm)	77.9				
	SSM 1 METALS		**SSM 2 METALS**		**SSM 3 METALS**		**SSM 4 METALS**	
1	SOLIDIFICATION (LIME/FLY ASH)	96.8	SOIL WASHING (SURFACTANT 2mm)	96.4	SOLIDIFICATION (PORTLAND CEMENT)	99.4	SOIL WASHING (CHELATE 2mm)	93.3
2	SOLIDIFICATION (PORTLAND CEMENT)	95.2	SOIL WASHING (CHELATE 2mm)	94.7	SOIL WASHING (CHELATE 0.25-2mm)	95.5	SOIL WASHING (SURFACTANT 2mm)	92.6
3	SOLIDIFICATION (KILN DUST)	95.1	SOIL WASHING (WATER 2mm)	94.6	SOIL WASHING (CHELATE 2mm)	88.7	SOIL WASHING (WATER 2mm)	87 4
4	SOIL WASHING (SURFACTANT 2mm)	88.6	SOIL WASHING (CHELATE 0.25-2mm)	92.2	SOIL WASHING (WATER 2mm)	87.4	SOLIDIFICATION (PORTLAND CEMENT)	85.3
5	SOIL WASHING (WATER 2mm)	87.4	SOLIDIFICATION (LIME/FLY ASH)	92.1	SOIL WASHING (WATER 0.25-2mm)	84.1	SOIL WASHING (CHELATE 0.25-2mm)	76.9
6	SOIL WASHING (SURFACTANT 0.25-2mm)	83.8	SOLIDIFICATION (PORTLAND CEMENT)	83.0	SOLIDIFICATION (KILN DUST)	83.7	SOIL WASHING (SURFACT 0.25-2mm)	70.0
7	INCINERATION	80.5	LOW TEMP THERMAL DESORB @ 150 F	82.0	SOLIDIFICATION (LIME/FLY ASH)	54.3	SOLIDIFICATION (LIME/FLY ASH)	68.3
8	CHEMICAL TREATMENT (KPEG)	78.4	SOIL WASHING (SURFACT 0.25-2mm)	76.2	CHEMICAL TREATMENT (KPEG)	35.0	SOIL WASHING (WATER 0.25-2mm)	67.1
9	SOIL WASHING (WATER 0.25-2mm)	76.3	SOLIDIFICATION (KILN DUST)	71.2			SOLIDIFICATION (KILN DUST)	66.4
10			INCINERATION	64.3			CHEMICAL TREATMENT (KPEG)	48.7

whole, the data for the different technologies indicated that TCLP could be used (with some qualifications) to judge treatability and performance.

There are, however, a number of areas concerning TCLP that should be explored and considered before utilizing this technique. Table 2 shows the amount of hazardous material that can be extracted from an untreated soil, and for the metals and volatiles it was about 30 and 50 percent respectively. TCLP is an aqueous extraction, and if the material to be monitored is only partially extracted in the aqueous fraction the quality of the data will always be subject to criticism. The problem was quite evident in this study where the initial concentration of arsenic, chromium, anthracene and bis(2-ethylhexyl) phthalate were close to the detection limits of the analytical technique used to monitor the compounds. Making decisions on treatment efficiency based on the difference between two small numbers can be risky, and it is recommended that compounds in this category be excluded or minimum soil concentrations for these compounds be established before treatment begins.

Along the same line as discussed above, soils at each Superfund site are going to be different and the extractability of hazardous compounds by TCLP will also vary. The extraction coefficient for the contaminant of concern needs to be determined for each site before a decision on the use of TCLP for monitoring treatment can be made.

However, even with some solubility drawbacks, when approaching TCLP from a health and safety standpoint, its impact is quantitated better. Earlier in this paper some health effects data was reported relative to the drinking water standards. These guidelines can be applied to the TCLP numbers generated from this study. If this is done, the only problem areas are: volatiles and semivolatiles associated with stabilization and low temperature thermal desorption plus the cadmium metals from low temperature thermal desorption. Since individual treatment technologies seem to be oriented towards particular problems (i.e. organics/thermal) in the real world, not all of these technologies would be applied to all the components in a waste soil. Stabilization, for example, would not be applied to a soil with significant organics (perhaps 1% or more), thus the TCLP problems identified with this treatment/contaminant pair would not be seen. Low temperature thermal desorption might only be applied to soils with volatiles or very low concentrations of cadmium salts.

To summarize the TCLP data used to monitor treatment effectiveness and to put it into perspective, Table 9 was prepared to show all the data that was collected around the five technologies and four SSMs in order of apparent treatment effectiveness. The table suggests that if TCLP were to be used as the indicator of treatment and performance, then the thermal technologies and soil washing would be most effective for treating volatiles in soils; soil washing, solidification, chemical and incineration would be effective for semivolatiles, and solidification would be most effective for treating metals.

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